Combining New and Conventional Sensors To Study the Balearic Current

The SINOCOP Experiment Improves Understanding Of Coastal Mesoscale Processes in the Western Mediterranean Sea

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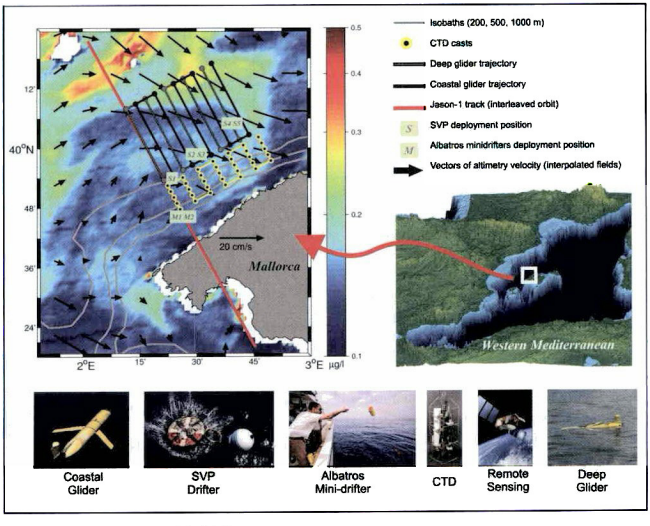
New monitoring technologies are being progressively implemented on coastal ocean observatories. As an example, autonomous underwater vehicle (AUV) technology allows high-resolution sampling that shows the existence of features like submesoscale eddies with intense vertical motions, an issue of worldwide relevance in a climate change context. These observatories are providing insight into coastal ocean variability, which will trigger new theoretical de-velopments, increasing understanding of coastal and near-shore processes and contribute to more science-based and sustainable management of coastal areas.

Research and technology development in the Balearic Islands over the last 20 years have significantly contributed to understanding various oceanographic problems of worldwide interest.

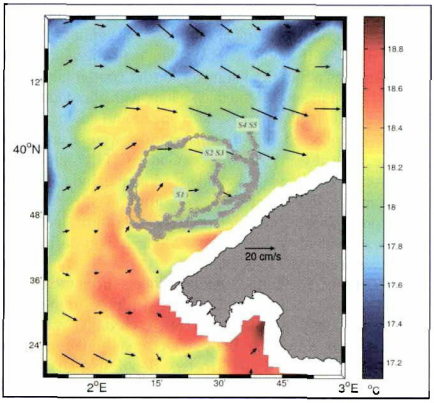
Also important are both the strategic position of the Balearic Islands in the Western Mediterranean Sea and the nature of this semienclosed sea, an ideal reduced-scale ocean laboratory, where processes (such as thermohaline circulation, deep convection, shelf/slope exchanges, mesoscale and submesoscale dynamics, coastal interactions, etc.) can be studied on a smaller scale than in other oceanic regions, since it has an internal Rossby radius on the order of 10 kilometers.

Physical mechanisms are thus better monitored and understood in this ocean basin, advancing knowledge of physical interactions and biogeochemical coupling at nearshore, local, sub-basin and global scales.

To properly address the new scientific challenges associated with coastal marine variability (including physical, biogeochemical and ecosystem processes), a sustained, routine and multiplatform observational program is needed. This is one of the key conclusions and recommendations reached



Sketch of the sampling design. Vectors correspond to absolute geostrophic velocities from altimetry, and the color field represents chlorophyll from MODIS for May 16, 2009.



Drifters' trajectories between May 11 and May 21 in 2009. Vectors correspond to absolute geostrophic velocities from altimetry, and the color field represents SST for May 16, 2009.

during the recent OceanObs09 Conference, held in September of last year in Venice, Italy.

SINOCOP Experiment

The National Spanish Research Council's SINOCOP (which stands for "toward an integrated system of coastal operational oceanography" in Spanish) experiment was designed to develop new methodologies to estimate the 3D state of the ocean using a multisensor observational approach combined with numerical modeling.

Observations include the use of coastal and deep-sea gliders; drifters; standard conductivity, temperature and depth sensors (CTDs); and remote sensing (monitoring for altimetry, sea surface temperature [SST] and ocean color). Besides the general goal, the specific scientific and technological objectives are to investigate the limitations and suggest potential improvements to different radar altimetric data sets in the coastal area, to develop new methods for the combination of different sensors and to use high-resolution observations (from gliders) together with numerical results to study the formation, evolution and decay of mesoscale and submesoscale features.

The SINOCOP experiment was carried out along the northwest coast of Mallorca Island in the Western Mediterranean from May 11 to 21, 2009.

The multisensor sampling strategy allowed researchers to investigate the mesoscale and submesoscale processes associated with the Balearic Current, the main oceanographic feature of the area.

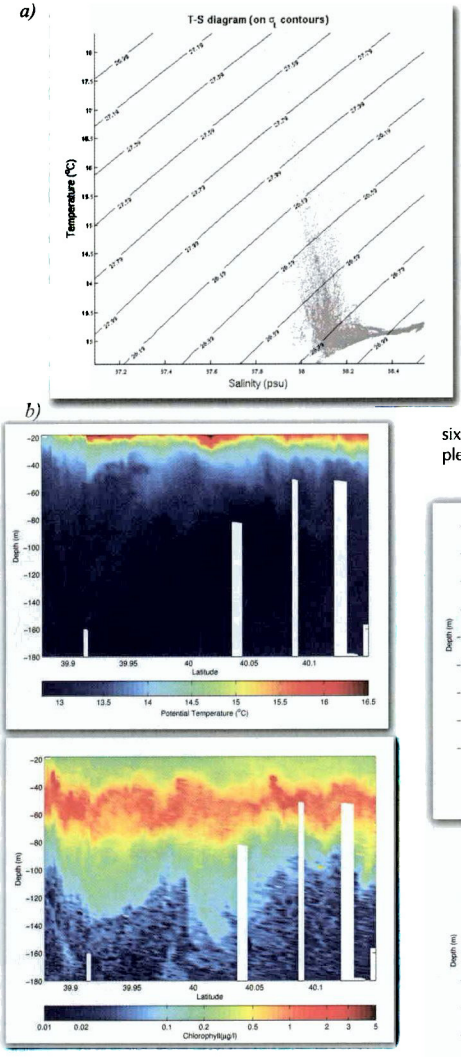
New and Conventional Technologies

Gliders. A mission using two Teledyne Webb Research (East Falmouth, Massachusetts) Slocum gliders was carried out simultaneously and in combination with other types of measurements (from drifters, ship-mounted CTDs and remote sensing). The gliders are AUVs providing high-resolution hydrographic and biogeochemical measurements. The net

horizontal speed of these vehicles is about one kilometer per hour, taking into account when they are at the surface to transmit data. In this experiment, the coastal glider operated between the surface and 200 meters while the deep glider (with a maximum depth of 1,000 meters) was set to reach 600 meters. The autonomous platforms covered an area of 50-by-40 kilometers, collecting 811 hydrographic (temperature and salinity) and biogeochemical (turbidity, oxygen and chlorophyll) profiles. The horizontal resolution in the along-track direction was about 0.3 kilometer for the coastal glider and about 1.1 kilometers for the deep glider, with about four kilometers between glider tracks. Both upcast and downcast profiles were collected, and the final profiles were averaged in the vertical every one meter. Glider CTD profiles were processed following a standard approach and calibrated against independent CTD casts from an SBE 25 probe (from Bellevue, Washington-based Sea-Bird Electronics Inc.) installed on the Instituto Mediterráneo de Estudios Avanzados (IMEDEA) ship.

Drifters. Five surface velocity drifters from Clearwater (Watertown, Massachusetts) were deployed in the study area to measure surface currents. Each drifter was composed of a surface buoy with a subsurface drogue attached, centered at 15 meters' depth, that guaranteed the flow of the drifter with the ocean currents (minimizing the effect of wind). A transmitter inside the surface buoy periodically sent positioning data for tracking surface ocean trajectories using the Argos-2 communication system.

Positioning time series data from drifters were linearly interpolated every six hours and a low-pass filter with a 36-hour cutoff frequency was applied in order to remove inertial oscillations. The drifters' velocity was calculated by measuring the time difference between the processed six-hour positions. Finally, the time-series data were subsampled every 24 hours to obtain a daily product.



a) Temperature-salinity diagrams from deep glider data.
b) Clockwise, from top left: Potential temperature, salinity, oxygen and chlorophyll data from the first transect of a coastal glider.

In addition to the drifters described above, two Albatros Marine Technologies (Esporles, Spain) minidrifters (20 centimeters in length with a 10-centimeter diameter) were deployed on the 200-meter isobath. Their small size minimizes the risk of collisions with maritime traffic. The buoys use Global System for Mobile Communications short message service communications.

Remote Sensing: Altimetry and SST. In this study, 2D interpolated gridded fields, currently delivered by Collecte Localisation Satellites' Aviso Web server, were used. The gridded fields are specific to the Mediterranean Sea and are computed on a regular 1/8° grid using a suboptimal space/time optimal interpolated analysis. In a future study, improved coastal altimeter products resulting from the application of specific geophysical corrections and review of the data recovery near the coast will be analyzed.

Regarding SST satellite data, raw images at 1.2-kilometer resolution acquired and processed by Gruppo di Oceanografia da Satellite-Istituto di Scienze dell'Atmosfera e del Clima-Consiglio Nazionale delle Ricerche (GOS-ISAC-CNR), as well as six-hour averaged images at two-kilometer spatial resolution from the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Web server, were available during the experiment. Ocean color images from the Moderate Resolution Imaging Spectroradiometer (MODIS) were processed and delivered by GOS-ISAC-CNR.

Shipboard CTDs. Twenty-four CTD casts (using the SBE 25 probe) were performed from IMEDEA's coastal ship. The sampling covered the coastal zone between the isobaths of 200 and 1,000 meters. The distance between stations was 2.5 kilometers along the same transect and 6.5 kilometers between consecutive transects. Standard CTD processing was applied, and final profiles were interpolated with a vertical resolution of one meter.

Results and Perspectives

For the first time in the Balearic Sea, a multisensor experiment combining two gliders (one for deep water and one for coastal waters) with conventional technologies (CTDs from ships, drifters and satellites) has been successfully carried out.

The preliminary analysis of the *in-situ* and remote sensing data reveals the presence of an anomalous anti-cyclonic eddy near the northwest coast of Mallorca island of about 60 kilometers' diameter. This structure blocked the usual path of the Balearic Current along the coast, deflecting the main north-eastward flow to the north.

From drifter data analysis, horizontal velocities associated with the eddy have been estimated to be about 20 centimeters per second. Comparisons of drifter and altimetry data reveal that altimeter geostrophic currents derived from gridded products do not have sufficient resolution to detect these kinds of small mesoscale and submesoscale features.

This highlights the need for high-resolution altimetry measurements (e.g., through the future Surface Water and Ocean Topography mission).

Regarding the water samples collected in the area of study, the relatively fresh waters of Atlantic origin (37.4 practical salinity units) found in previous studies near the coast were not detected in this experiment. Instead, the signature of

Mediterranean water, which typically has a salinity of 38 practical salinity units and higher, was dominant in the study area.

It is also worth mentioning the presence of Western Mediterranean Intermediate waters, which are characterized by potential temperatures lower than 13° C. Furthermore, the glider data also gave some insights on Levantine Intermediate Waters, which are represented by salinity maxima higher than 38.4 practical salinity units.

A detailed analysis of the whole data set is in progress, including the modeling of these kinds of mesoscale structures. Particular attention will be devoted to the analysis of the biogeochemical data recorded by the glider platforms. The chlorophyll pattern will be analyzed in the context of the anomalous anti-cyclonic eddy detected in the study area, assessing the influence of this structure on the biogeochemical property distribution. This analysis will include the estimation of vertical motion, a key variable for improving understanding of the relationship between the physical and biological processes in the upper ocean.

The proposed research will give new insights on the variability of the Balearic Current and its impacts in controlling the coupling of physical and biogeochemical signals.

All these initiatives are in line with the new Sistema de Observación Costera de las Islas Baleares (SOCIB) coastal observing and forecasting system, a new facility that will address scientific and technological coastal ocean international priorities.

The system will be based in the Balearic Islands, but the data it collects will be of a more general interest for the global oceans, since the Mediterranean Sea can be considered to be an ideal, small scale ocean.

In the long term, multisensor experiments, such as the one presented here, will contribute to advancing the understanding of physical and multidisciplinary processes and their nonlinear interactions to detect and quantify changes in coastal systems, understand the mechanisms that regulate them and forecast their evolution and/or adaptation under, for example, different climate change scenarios.

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Ocean color images from MODIS were processed and delivered by GOS-ISAC-CNR.

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